

APPLICATIONS OF PARALLEL PROCESS HIMAP FOR LARGE SCALE MULTIDISCIPLINARY PROBLEMS

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Since the initiation of the HPCC Project at NASA in the early 90s, several computational tools have been developed under the computational aerosciences(CAS) area[1]. One such tool is HiMAP, a supermodular, 3-level parallel, portable high fidelity, tightly coupled analysis process[2,3]. This process is designed using the state-of-the-art information technology tools such as MPIRUN[4], an efficient protocol to allow groups of processors to communicate with other groups of processors for multidisciplinary type computations. MPIRUN is based on IEEE standard Message Passing Interface (MPI)[5] that is currently supported by most major computer vendors.

The modularity in HiMAP is based on the function of the individual discipline module. In general, an analysis process in HiMAP is divided into independent and dependent modules. Independent modules are those dealing with specific physics and can be used in stand alone mode as a single discipline code. For example, the fluids module is an independent module. Dependent modules are usually required for multidisciplinary computations. They depend on more than one module for their function. A typical example of a dependent module is thermal loads module in aero-thermoelastic computations. This module requires temperature data from the fluids module and also structural data from the structures module to convert temperature to thermal loads. Figure 1 shows a typical process chart for HiMAP.

The three level (intra-discipline, inter-discipline and multiple run) parallel capability is built into HiMAP using MPI and MPIRUN protocols. On a typical massively parallel super-computer, a set of processors are assigned to each discipline as needed. Communication within each discipline is accomplished using MPI. Between disciplines and cases communications are achieved using MPIRUN. Figure 2 shows the multi level parallel capability of HiMAP.

The hybrid coarse-fine grain parallelization achieves the goal of load-balanced execution provided that there are enough processors available to handle the total number of blocks. On the other hand, the load-balancing does not guarantee the efficient use of the computational nodes. The computational nodes might be working with less than the optimal computational load and performing a lot of expensive inter-processor communications, hence data-starved. Both problems are alleviated by introducing domain-coalescing capability to the parallelization scheme. In domain coalescing, a number of blocks are assigned to a single processors resulting in economy in number of the computational resources and also a more favorable communications-to-computations ratio during the execution. This process which is illustrated in Fig. 3 is described in Ref. 6 that was presented at SC97.

HiMAP is suitable for large scale multidisciplinary analyses. It incorporates Euler/Navier-Stokes based flow solvers such as ENSAERO[7], USM3D[8] and finite element based structures solvers such as NASTRAN[9]. To-date HiMAP has been demonstrated for large scale aeroelastic applications that required 16 million fluid grid points and 20,000 structural finite elements. Cases have been demonstrated using up to 228 nodes on IBM SP2 and 256 nodes on SGI Origin2000 computers. Typical configurations analyzed are full subsonic and supersonic aircraft.

Figure 4 shows the 34 block grid for the sub-scale wind tunnel model of an L1011 transport

aircraft[10,11]. The total grid size is 9M points. Due to geometric complexity grid sizes vary significantly from block to block. The ratio of smallest to largest grid size is 0.07. This distribution can lead to inefficient computations on MPP. An algorithm based on node filling is currently incorporated in HiMAP. This algorithm assigns multiple grids to a single processor. Using the node filling algorithm that will be explained in detail in the full paper, the 34 block grid was mapped on to 24 Origin-2000 processors. Figure 5 shows the original grid distribution by assigning one block per processor and modified block distribution by using the node-filling algorithm. The computational efficiency is increased by 30% with the new distribution. Further research is ongoing in using neural networks approach for load balancing.

Fig 6 shows one of the 5 structural modes from the finite element computations. One O2000 node was assigned to the modal data. Computations were made using GO3D (Goorjian-Obayashi Streamwise Upwind Algorithm) fluids solver[12] and ENSAERO modal solver[13] along with MBMG(MultiBlockMovingGrid)[11,14] moving grid module available in HiMAP process. A typical aeroelastic solution is shown in Fig 7. The stability and convergence of GO3D algorithm was not affected by re-distribution of patched grids to different processors. Figure 8 shows a plot of current grid size versus grid blocks. This grid is for a complex state-of-the-art aircraft.

HiMAP is multi-platform middleware. It has been tested on IBMSP2, SUN HPC6000 and SGI O2000 systems. Scalable performance and portability is shown in Fig 9. Work is in progress to port HiMAP to other latest platforms such as SGI O3000.

Current effort is in progress to apply HiMAP for aeroelastic computations of more complex configurations than presented in this paper. Future work involves efforts to map HiMAP on to PSE (Problem Solving Environment) and IPG (Information Power Grid) tools.

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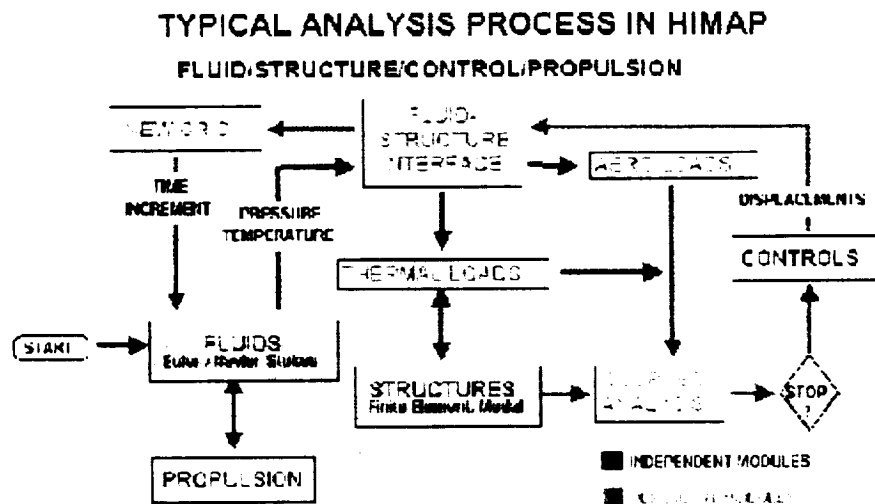


Fig.1 Parallel Process

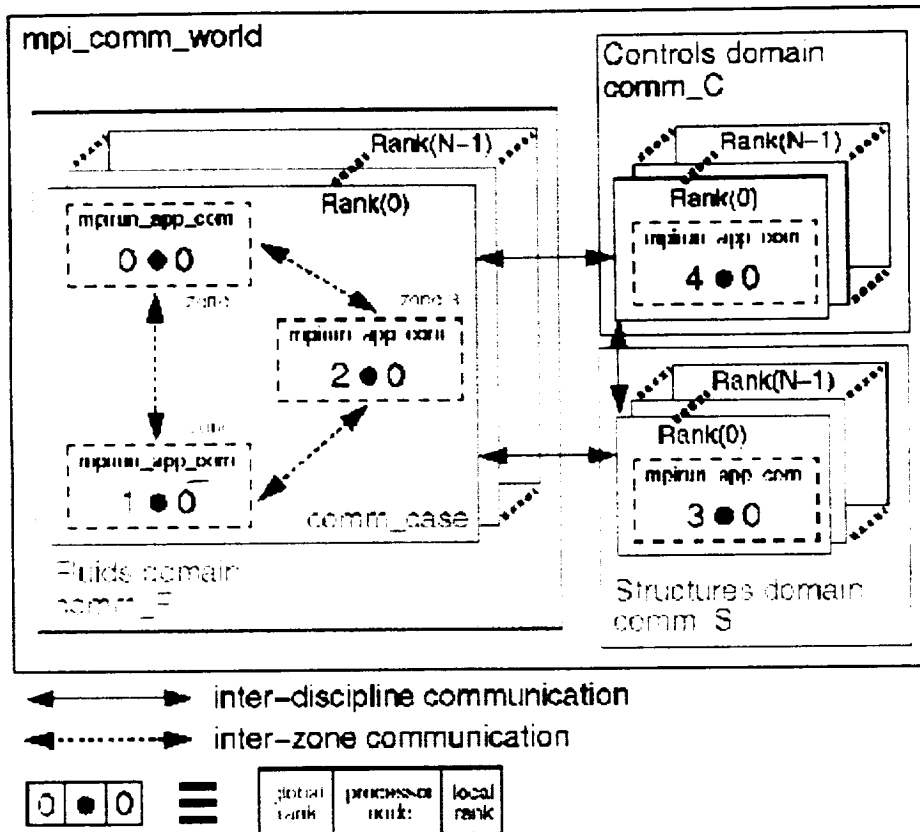


Fig.2 Multilevel process

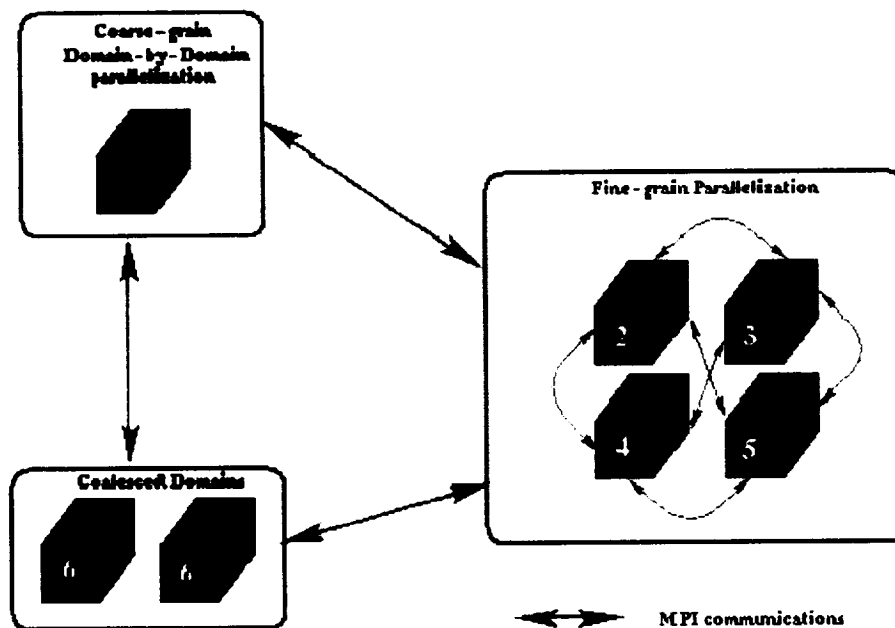


Fig.3 Load balacing approach in HiMAP

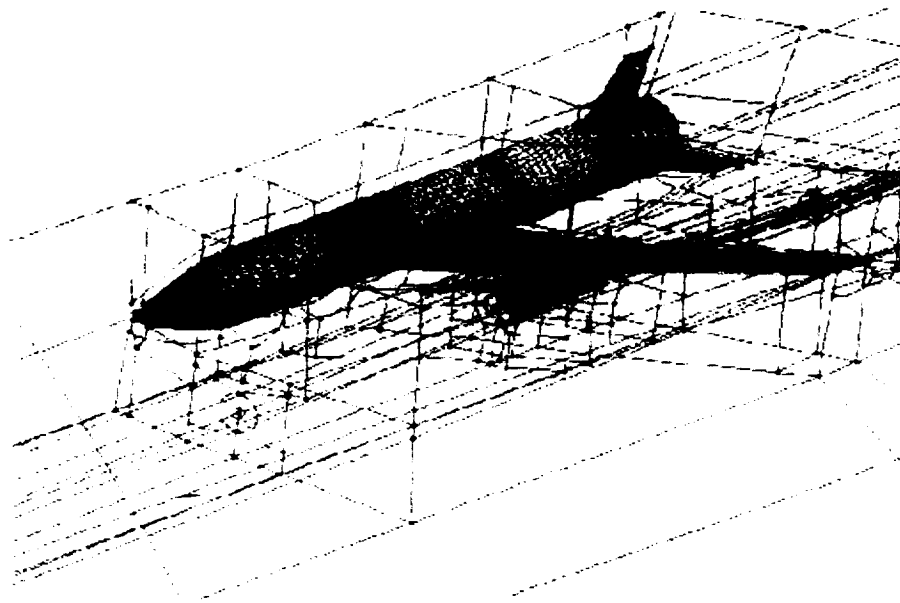


Fig.4 Grid Blocks for L1011 wind tunnel mode

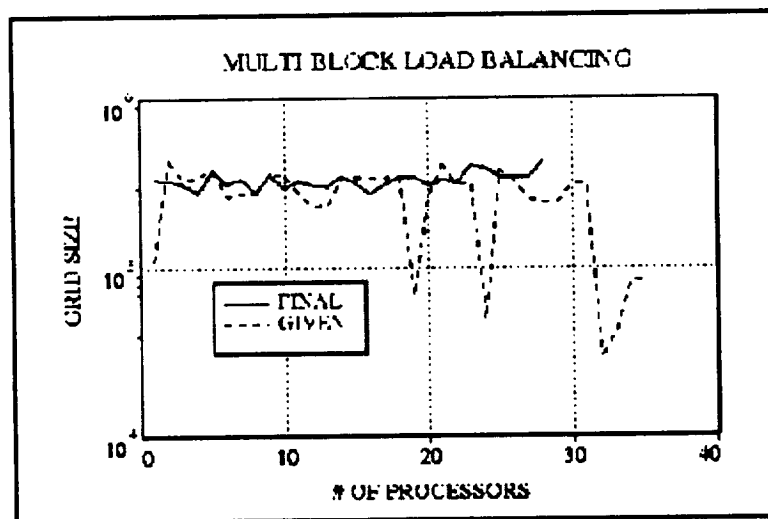


Fig.5 Results load balancing

L1011 mode 2

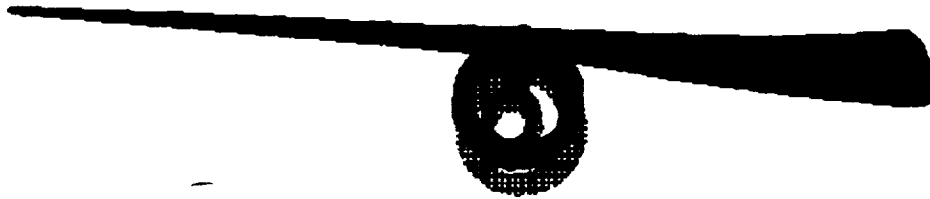


Fig.6 Modal data from finite element analysis

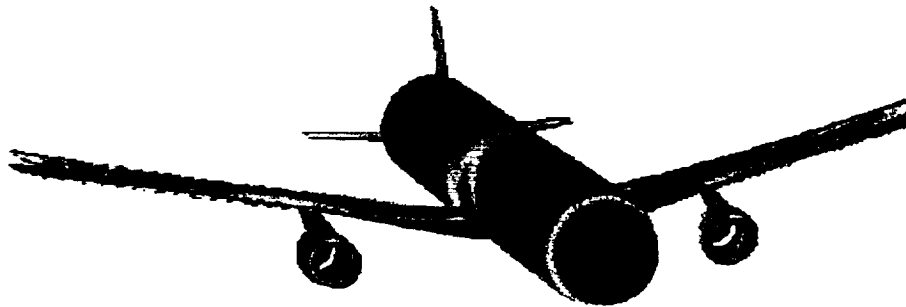


Fig.7 Typical aeroelastic results for L1011 sub-scale wind tunnel model

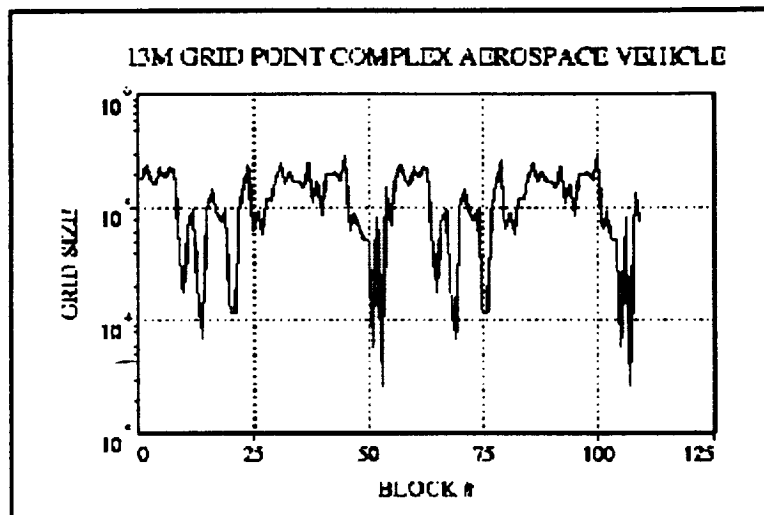


Fig.8 Grid distribution for a complex aerospace vehicle

PORTABILITY AND PERFORMANCE OF HiMAP

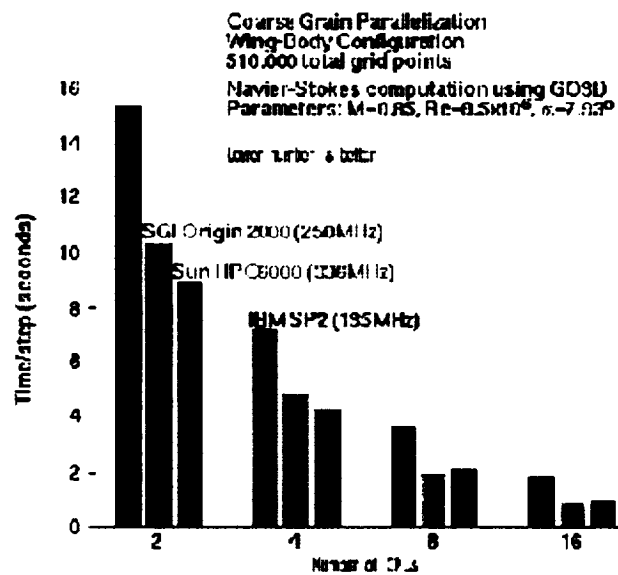


Fig.9 Demonstration of Portability of HiMAP

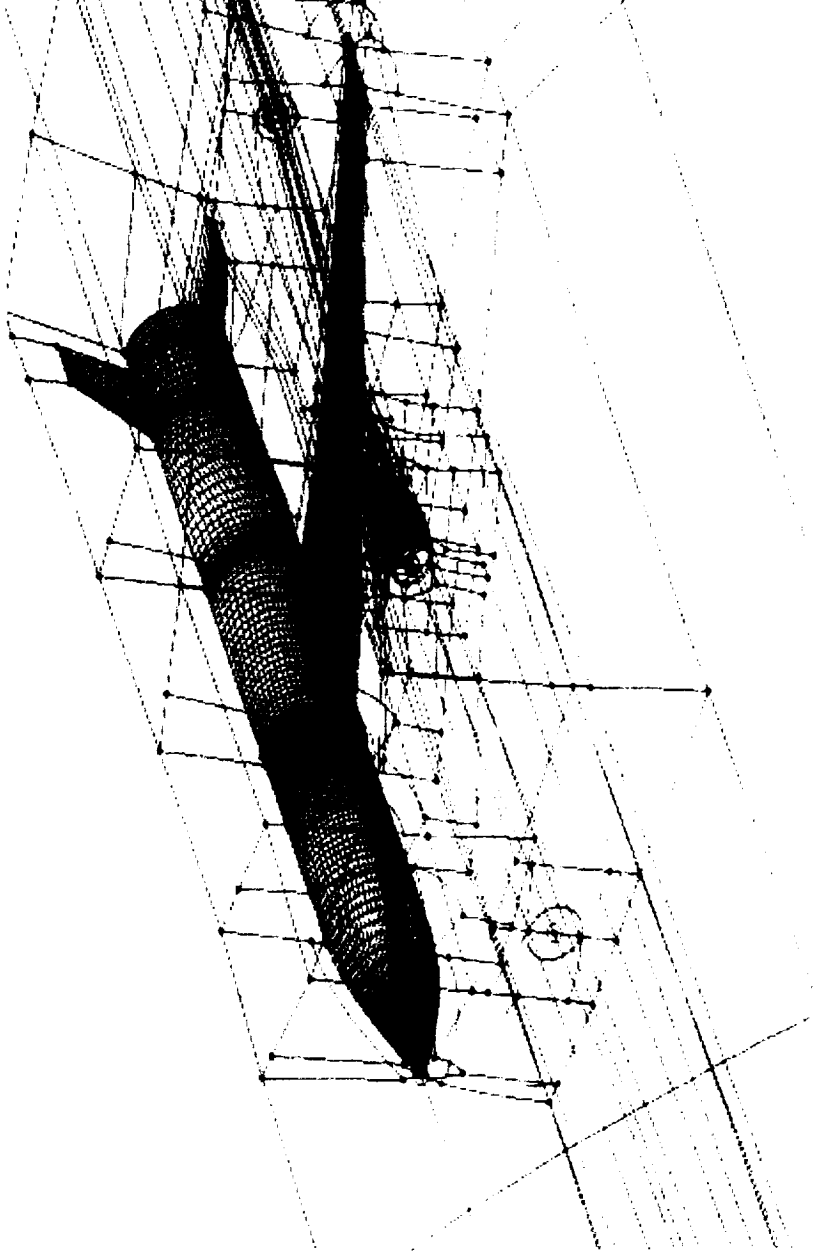
COUPLED COMPUTATIONS

WING-BODY-CONTROL AEROELASTIC COMPUTATION ON IBM SP2
8 FLUID NODES, 1 STRUCTURES NODE, 1 CONTROLS NODE

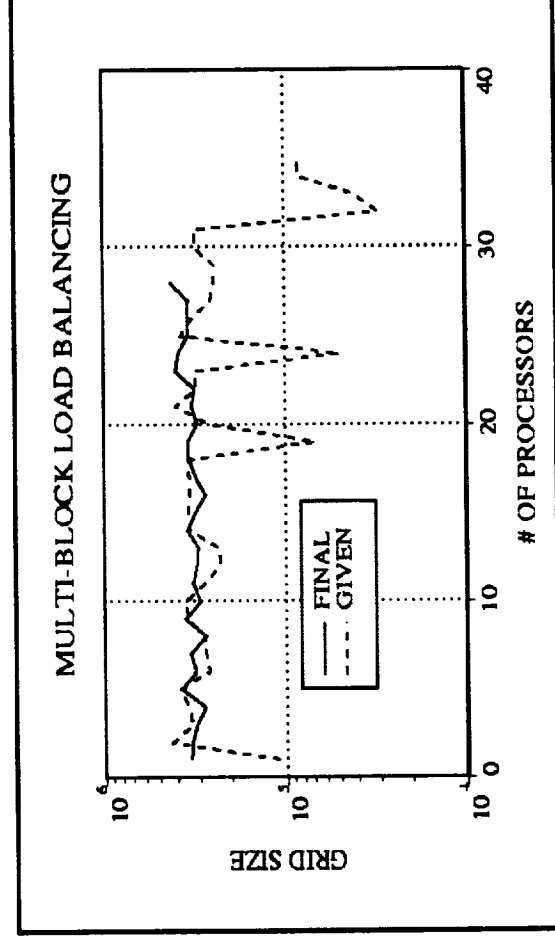


MULTI-BLOCK GRID FOR FLOW SOLVER

L1011 WIND TUNNEL MODEL
9 MILLION GRID POINTS, 34 BLOCKS



RESULTS FROM NODE FILLING ALGORITHM IN HIMAP



L1011 WIND TUNNEL MODEL, 9 MILLION GRID POINTS
NUMBER OF PROCESSORS REDUCED TO 28 FROM 34

MODAL STRUCTURAL DATA FOR L1011

12 MODES WITH 2100 DEGREES OF FREEDOM PER MODE

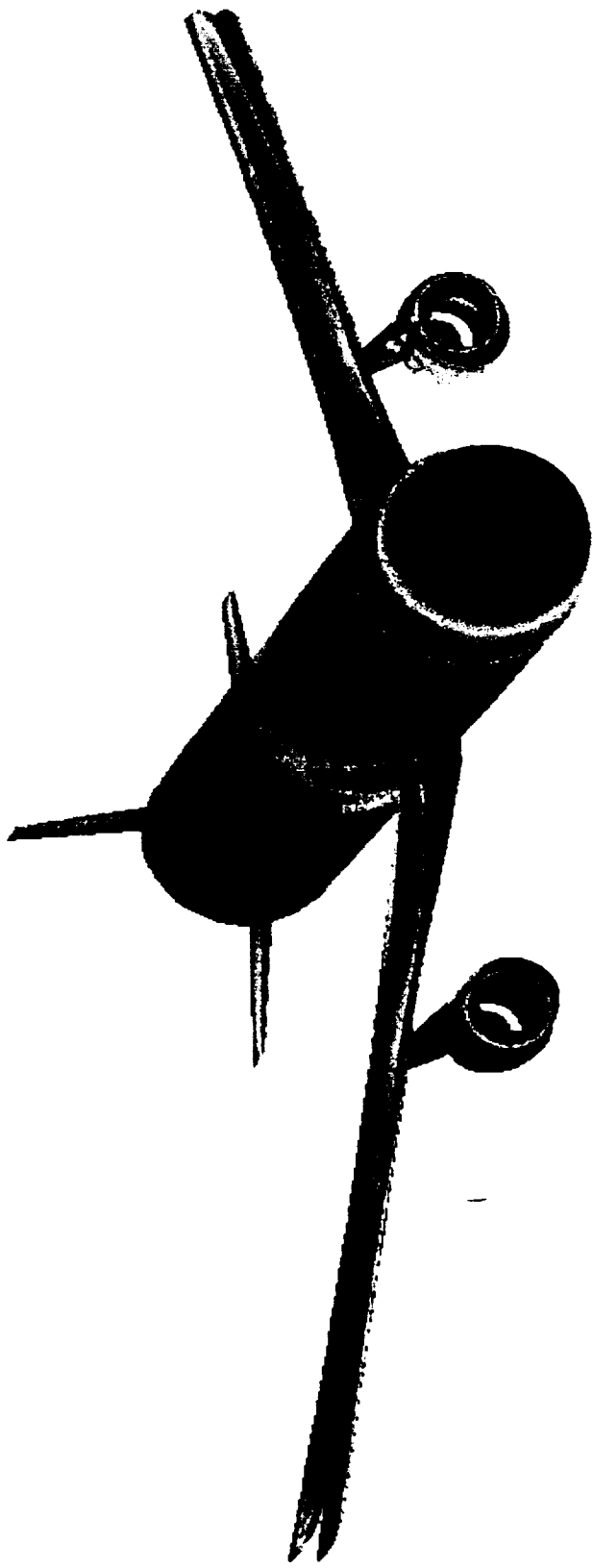
SECOND MODE

L1011 mode 2



LARGE SCALE DEMONSTRATION

**L1011 CONFIGURATION, 9M GRID POINTS, 35 NODES ON SGI/O2K
STATIC AEROELASTIC COMPUTATIONS, $M = 0.85$**



DEMONSTRATION OF CODE MODULARITY

(PLUG IN/OUT TYPE COMPUTATIONS)

STATIC AEROELASTIC ANALYSIS : HIMAP TEST CASE
USM3D FLOW SOLVER WITH MODAL STRUCTURES

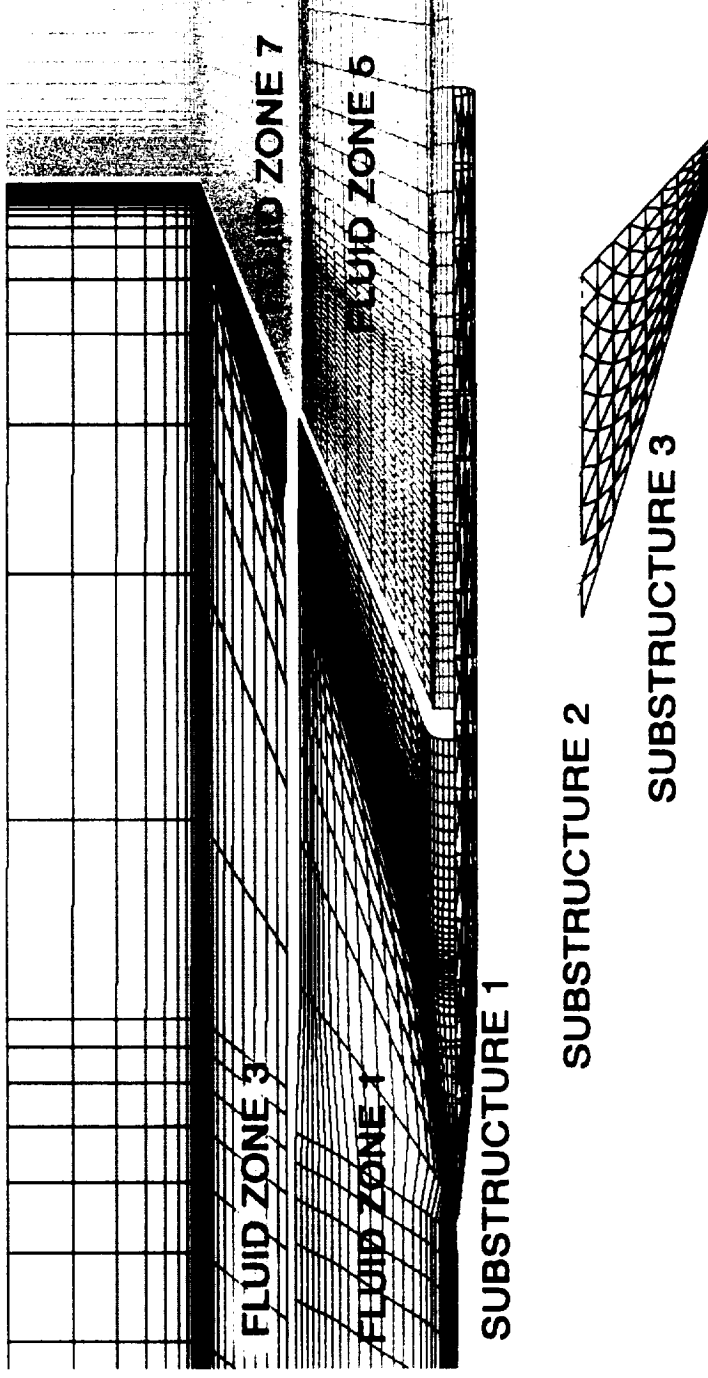


GRID STATISTICS:
CELLS = 384,239
NODES = 70,765

Paragon Research

MODULARITY IN FLUID/STRUCTURAL SOLVERS

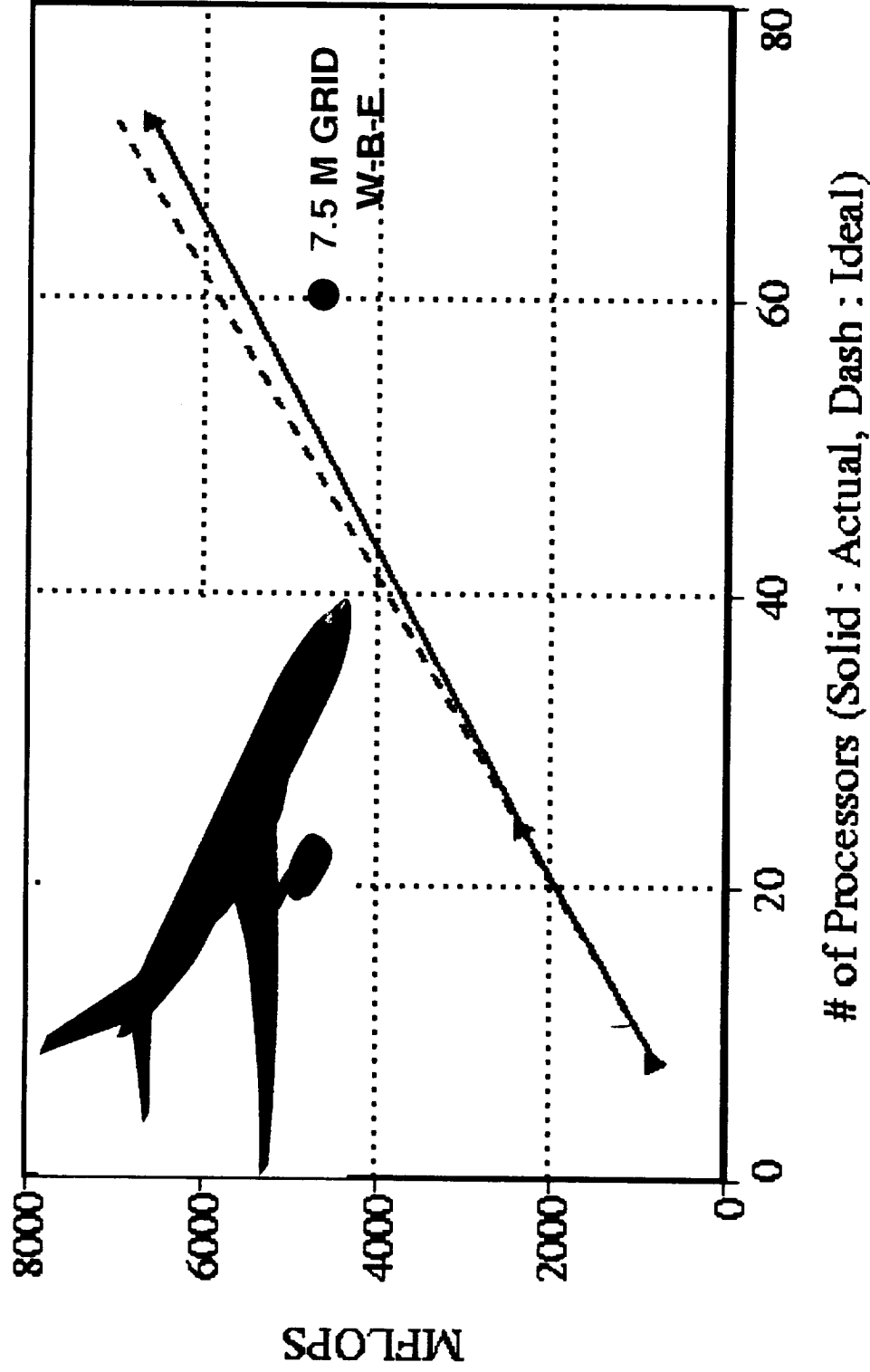
- ZONAL PATCHED FLOW GRIDS (ENSAERO, TLS3D, CFL3D, USM3D TYPE)
- SUB-STRUCTURE DATA BASE USING FE SOFTWARE (NASTRAN, COTS)
- SOLVE SUB-STRUCTURES IN PARALLEL COUPLED WITH PARALLEL FLOW (ARC3D/GO3D/USM3D) MODULE



- HIMAP IS TESTED UPTO 20K FE DATA USING NASTRAN AND ELFINI

SCALABLE PERFORMANCE

777 AIRCRAFT(W-B), 2.6 M GRID POINTS ON SGI O2000



**NOTE : 7.5 M GRID POINTS CASE RUNS AT 4.3 GFLOP USING 60 PROCESSORS
(USING R10000 CONFIGURATION WITHOUT OPTIMIZATION)**

**APPLICATIONS OF PARALLEL PROCESS HIMAP
FOR LARGE SCALE MULTIDISCIPLINARY PROBLEMS**

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NOVEMBER 2000
DALLAS, TEXAS**



OBJECTIVE

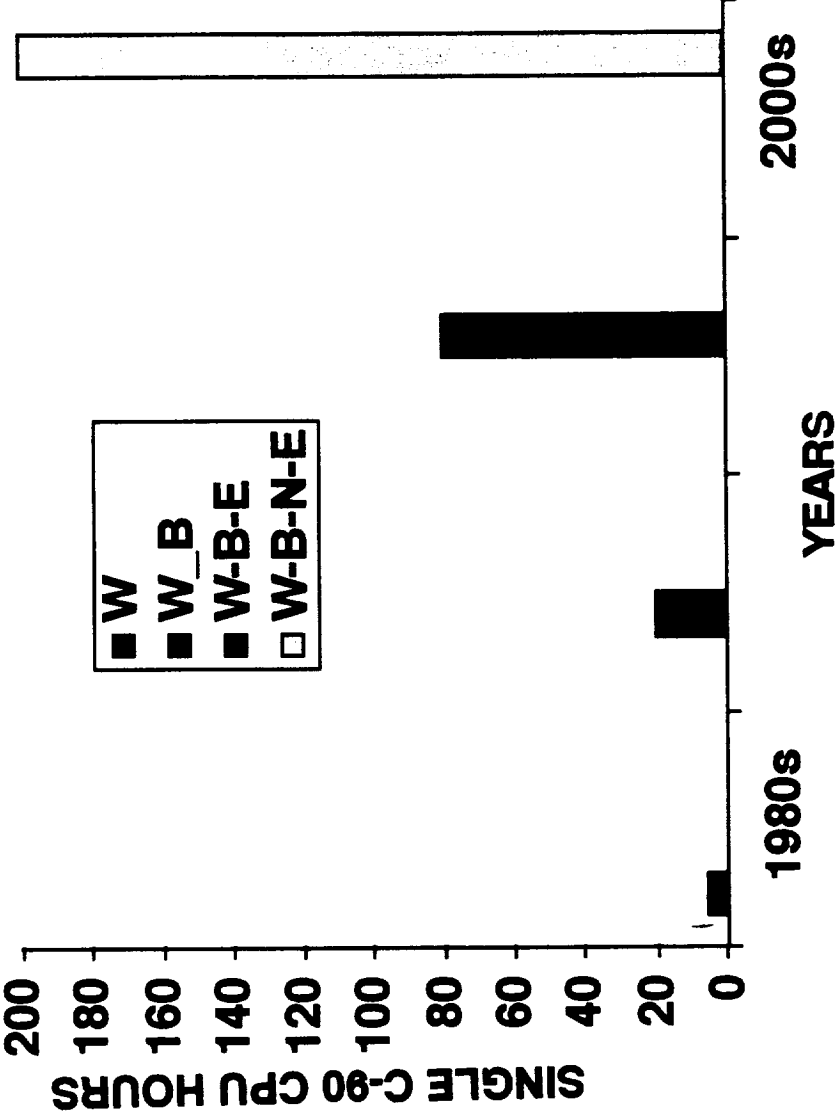
**DEVELOPE AND DEMONSTRATE A 3-LEVEL PARALLEL
MIDDLEWARE (HiMAP) THAT CAN BE INTERFACED TO LARGE
SCALE GLOBAL DESIGN ENVIRONMENT FOR CODE
INDEPENDENT, MULTIDISCIPLINARY ANALYSIS USING
HIGH FIDELITY EQUATIONS**

BACKGROUND

- **AEROSPACE TECHNOLOGY NEEDS ARE RAPIDLY CHANGING**
 - **NEEDS COMPUTATIONAL TOOLS FOR EFFICIENT/FAST DESIGN**
 - **NO INTEGRATED ANALYSIS AND DESIGN CAPABILITY PRESENTLY EXISTS BEYOND LOW - FIDELITY (JOHN MALONE, DIRECTOR ISE TRANSITION OFFICE)**
- **COMPUTATIONAL TOOLS COMPATIBLE TO REQUIREMENTS OF NATIONAL PROGRAMS SUCH AS SPACE TRANSPORTATION ARE NEEDED**
- **CONVENTIONAL COMPUTATIONAL TOOLS ARE INADEQUATE TO CATER FOR MODERN AEROSPACE DESIGN NEEDS**
 - **TOOLS ARE PHYSICS BIASED DEVELOPMENT**
 - **COMMUNICATE WELL ONLY AT LOW-FIDELITY LEVEL**
 - **NOT SCALABLE WITH HARDWARE**
- **ADVANCED COMPUTATIONAL TOOLS ARE REQUIRED**
 - **MODULAR**
 - **EFFICIENT COMMUNICATION AT HIGH FIDELITY**
 - **SEAMLESS INTEGRATION AMONG DISCIPLINES**
 - **PORTABLE AND SCALABLE WITH HARDWARE (MPP)**
 - **LEAD TO PAPERLESS DESIGN**
 - **CAPABLE OF 'TIGHTLY' AND 'LOOSELY' COUPLED SIMULATION**

BACKGROUND (CONTINUED)

GROWTH IN NEED OF CPU HOURS FOR AEROELASTICITY



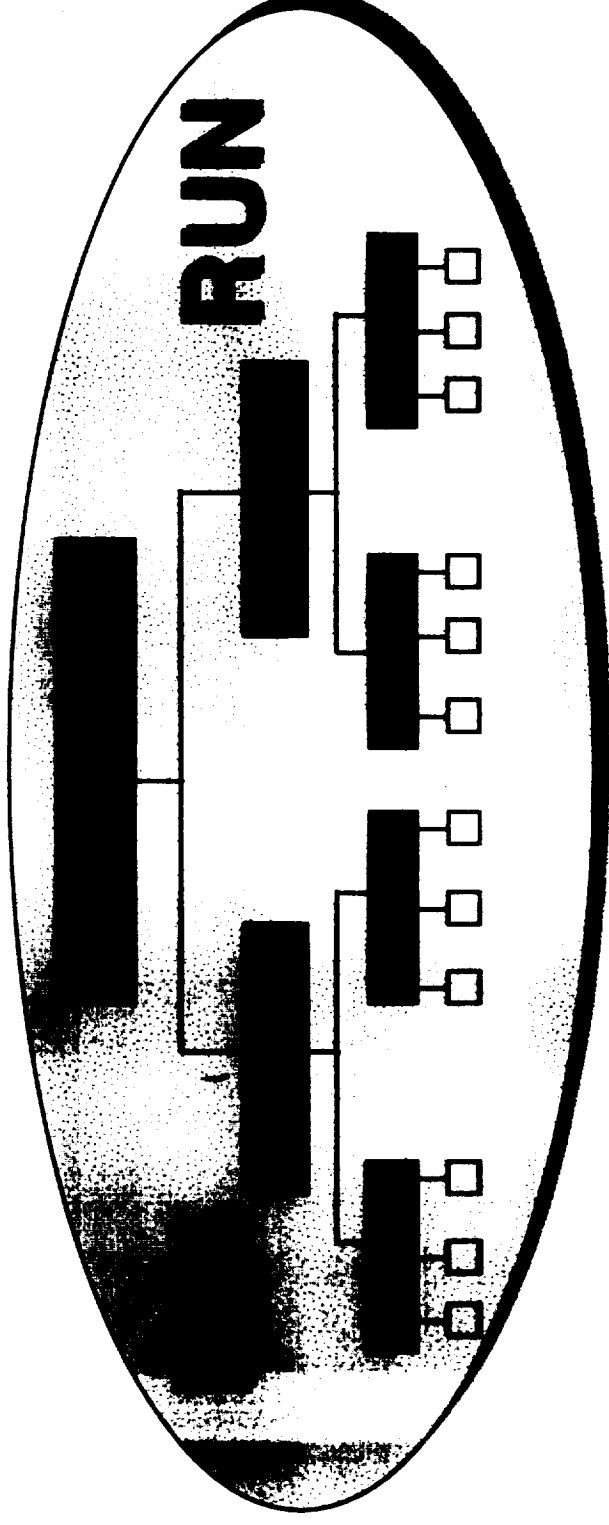
NOTE : TO SIMULATE ABOUT 5 SEC DYNAMIC RESPONSE DATA

APPROACH FOR HIMAP

- **DESIGN FOR WELL DEVELOPED AND ACCEPTED SINGLE DISCIPLINE TECHNOLOGIES THAT ARE SUITABLE FOR MODULAR DEVELOPMENT**
 - ZONAL GRID APPROACH FOR CFD
 - SUB-COMPONENT APPROACH FOR STRUCTURES
- **USE ONLY PORTABLE SOFTWARE, MIDDLEWARE AND PROCESS TOOLS (FORTRAN, C/C++, MPI, MPIRUN)**
- **MAINTAIN MODULARITY AT ALL STAGES**
 - SINGLE DISCIPLINE CODES
 - INTERFACES, WRAPPERS, FABRICS
 - HARDWARE
- **USE OBJECT-ORIENTED APPROACH AT ALL LEVELS**
 - HELPS MULTI-VENDOR/EXPERT DEVELOPMENT ENVIRONMENT
 - ALLOWS BLENDING OF GOTS AND COTS

SOFTWARE MODULARITY

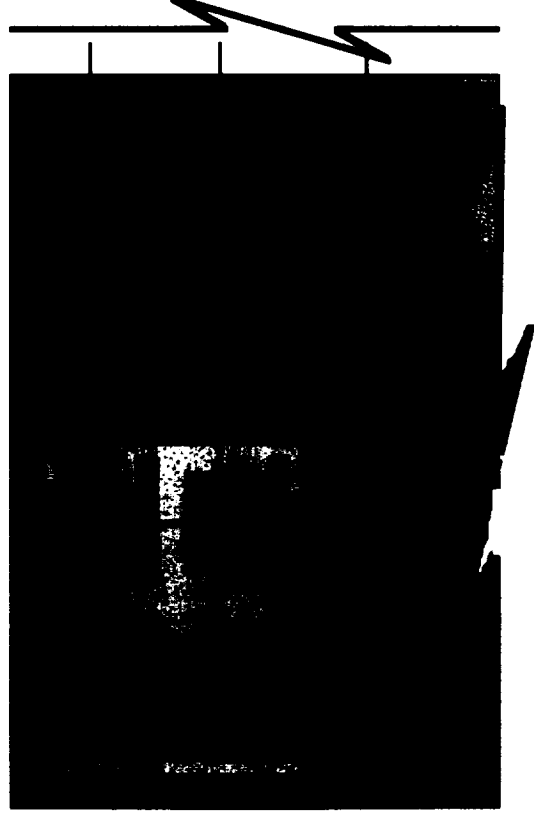
- AT SUB-MODULE LEVEL IN INDIVIDUAL DISCIPLINES
 - USE 'COMMON BLOCK' IN FORTRAN, GLOBAL VARIABLES IN 'C' (e.g TURBULENCE MODEL IN CFD, ELEMENT STIFFNESS IN FEM)
- MODULE LEVEL
 - USE 'BULK DATA' CONCEPT (NASTRAN)
- MODULE-MODULE WITH IN A DISCIPLINE
 - USE MODULAR HARDWARE (MPP) SUITABLE PROTOCOLS, MPI
- DISCIPLINE - DISCIPLINE AND CASE - CASE
 - USE 'MPIRUN' PROTOCOL



HARDWARE MODULARITY

- **MASSIVELY PARALLEL COMPUTERS (MPP), CLUSTERED WORK STATIONS ARE SUITABLE FOR MODULAR PROCESS DEVELOPMENT**
- **BUILT OUT OF MASS COMMODITY TYPE WORKSTATIONS**
- **USE MODULAR ARCHITECTURE**
- **SCALABLE PERFORMANCE**

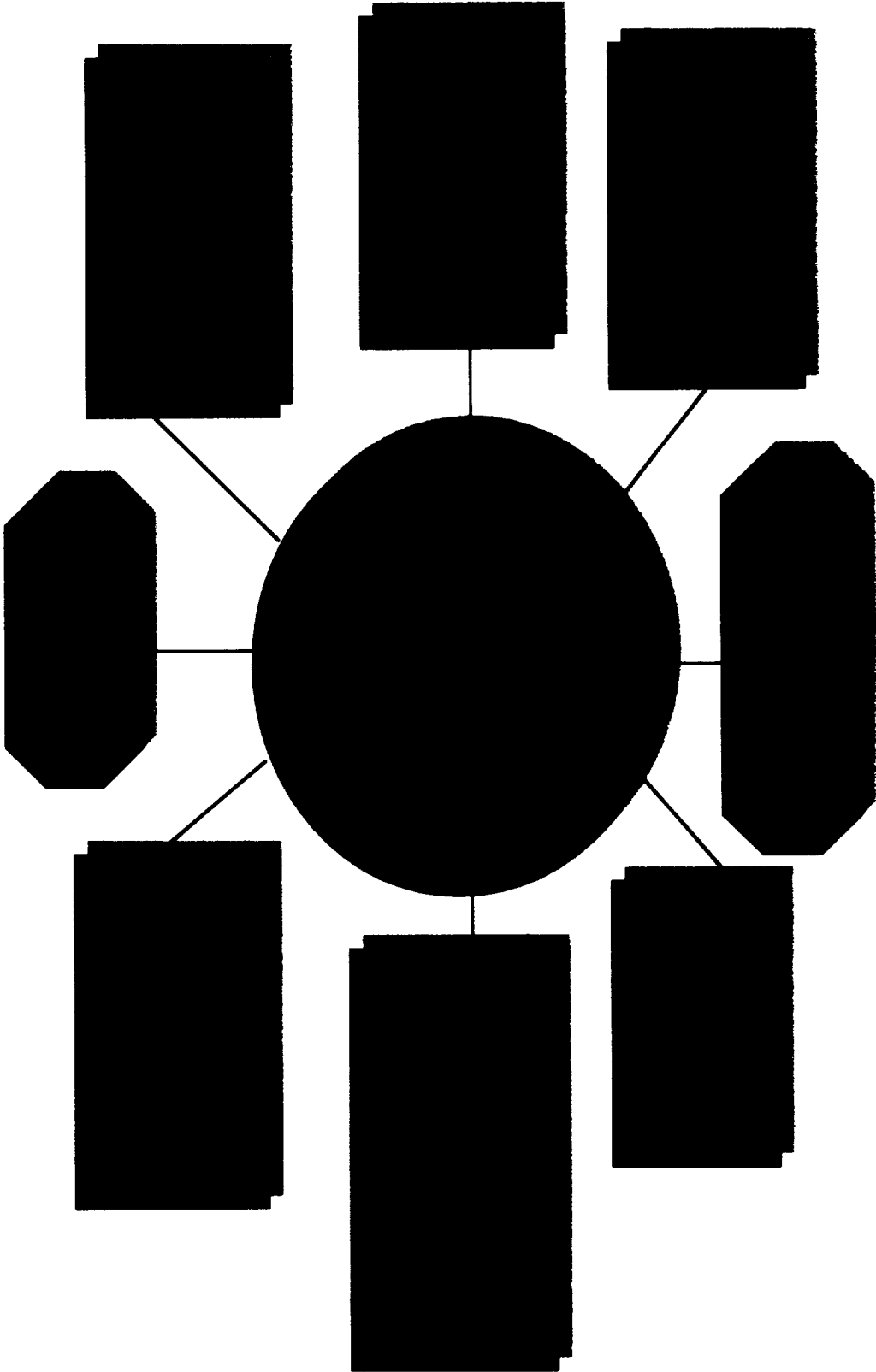
TYPICAL MODULAR MPP SYSTEM



**R10000 WORK STATION
195 MHz, 2GB PER 8 CPU**

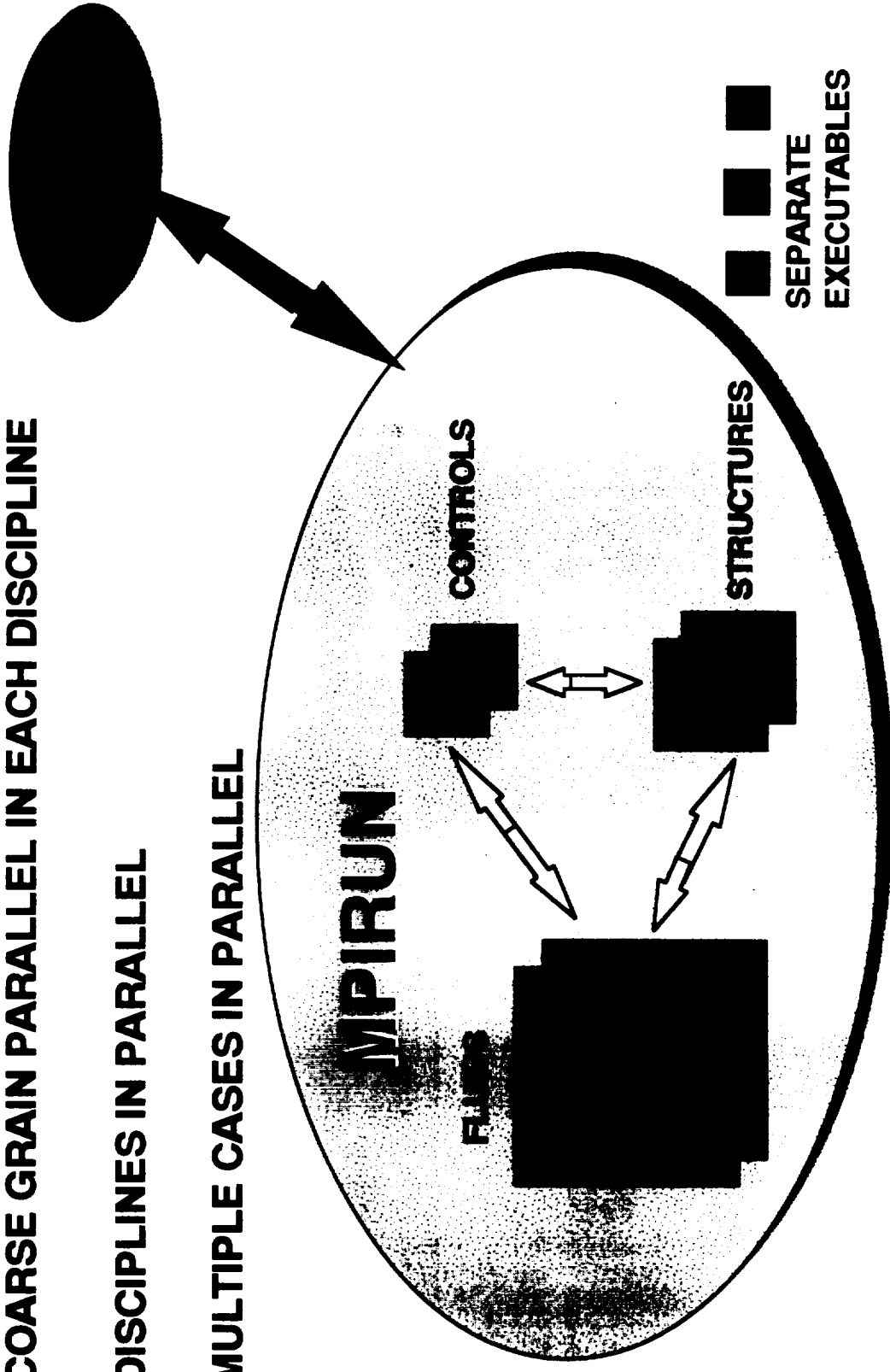
**SHARABLE MEMORY
CAN BE BUILT UP TO 512
PROCESSORS IN UNITS
OF 8 NODES**

HIMAP VISION CHART



THREE LEVEL PARALLEL PROCESS USING MPIRUN

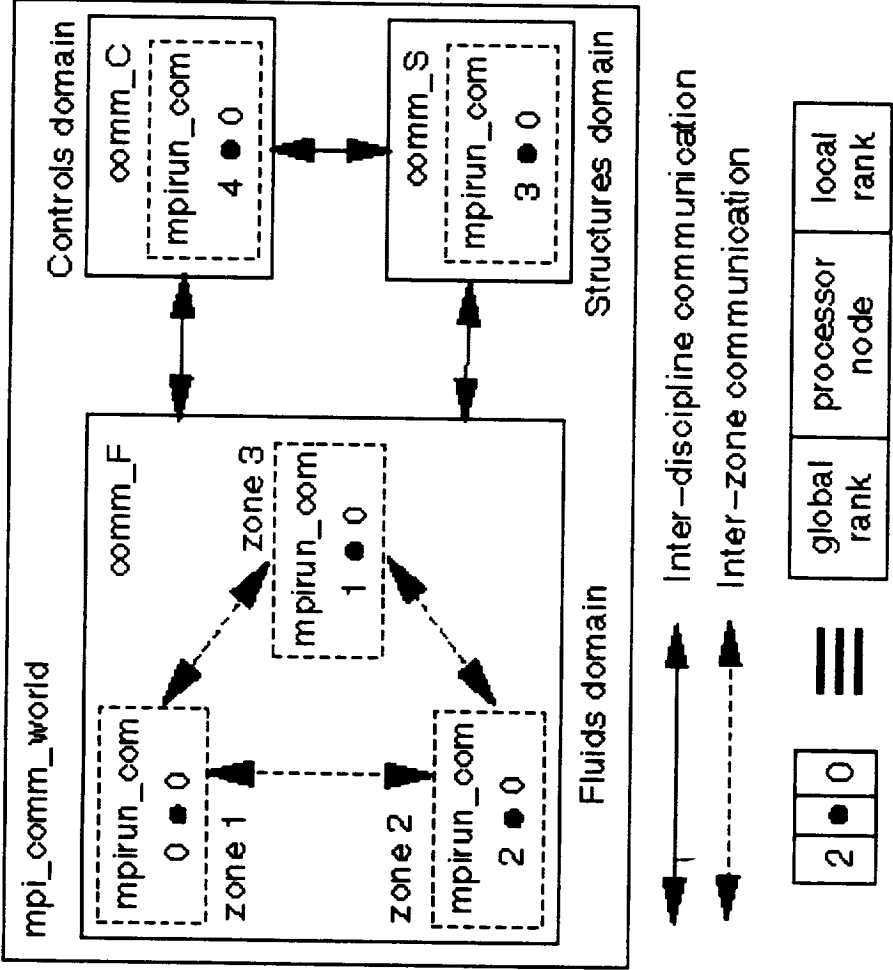
- COARSE GRAIN PARALLEL IN EACH DISCIPLINE
- DISCIPLINES IN PARALLEL
- MULTIPLE CASES IN PARALLEL



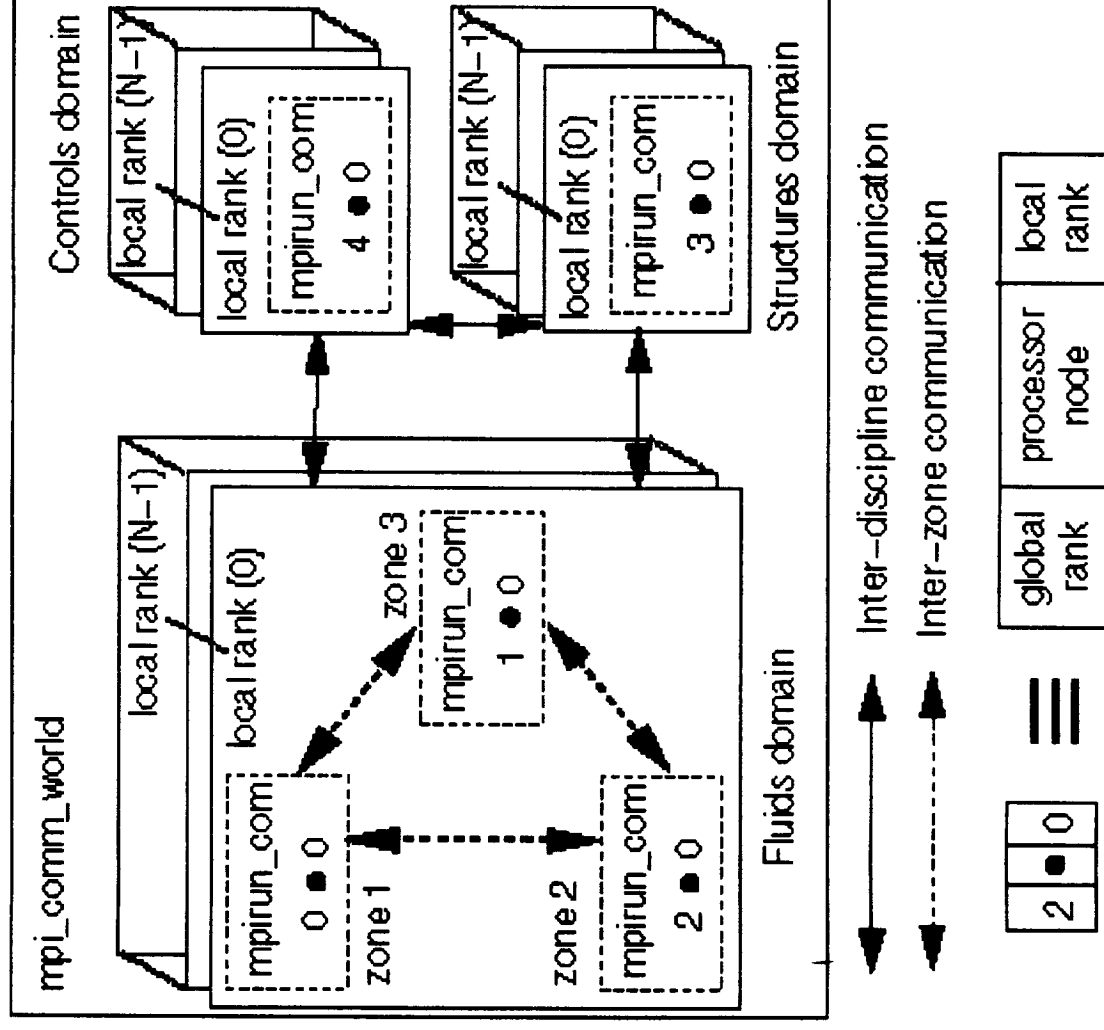
WHAT AND WHY IS MPIRUN ?

- **A PROTOCOL DEVELOPED BY HPCC/CAS PARALLEL TOOLS AND GRAND CHALLENGE GROUPS TO COMMUNICATE INFORMATION BETWEEN GROUPS OF PROCESSORS**
 - **USES IEEE STANDARD BASIC MPI**
 - **WRITTEN USING ANSI STANDARD 'C'**
 - **PROVIDES FLEXIBLE/GROUP COMMUNICATION**
 - **PORTABLE**
 - **SUITABLE FOR MULTIDISCIPLINE COMPUTATIONS**

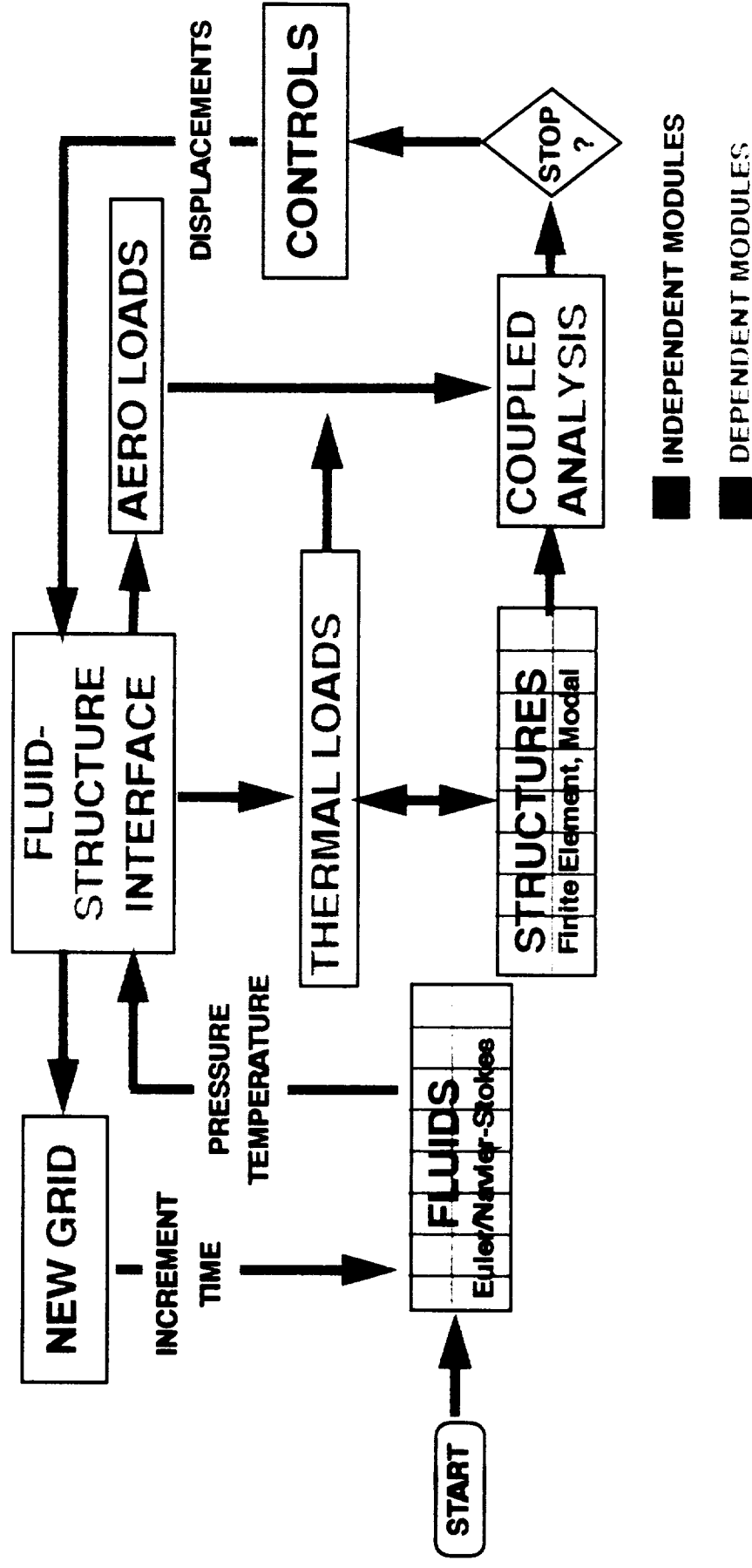
MULTIZONAL DATA COMMUNICATION PROCESS IN HIMAP



MULTIDISCIPLINE DATA COMMUNICATION IN HIMAP

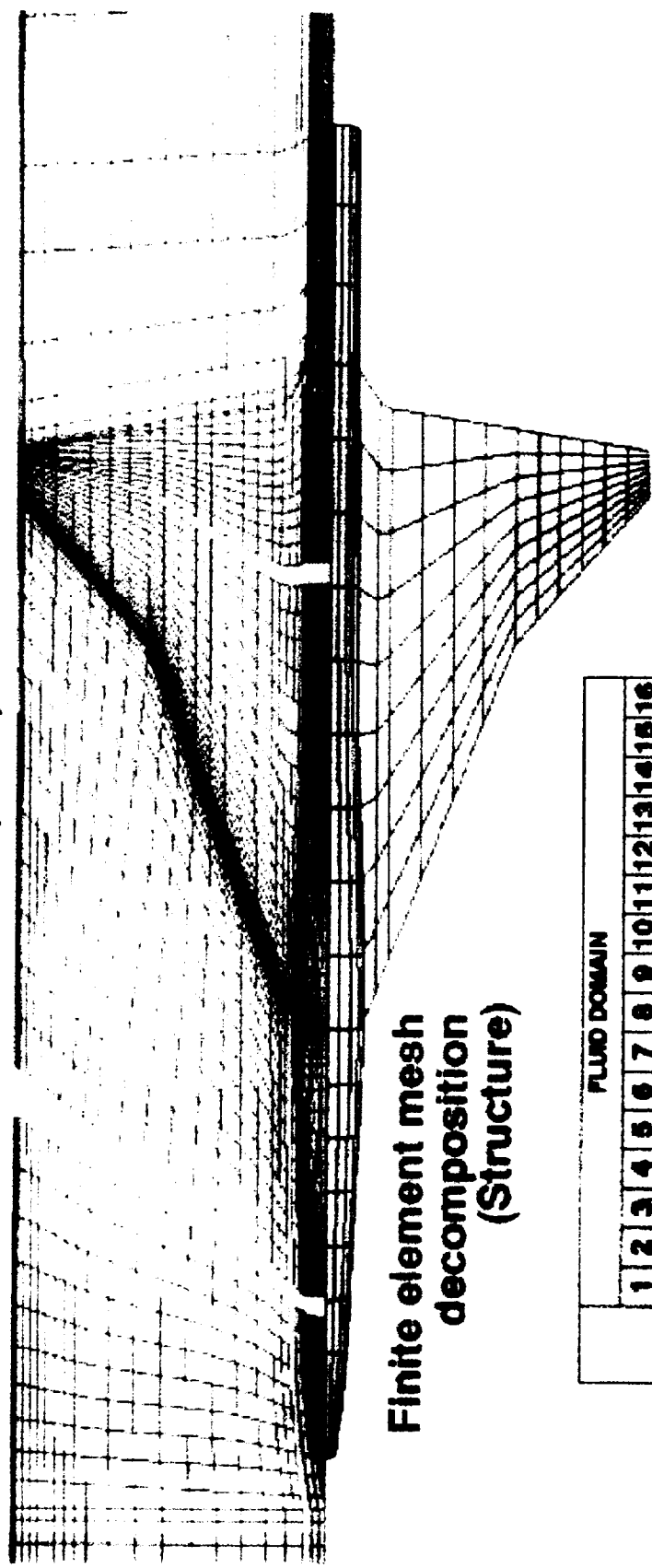


FLUID/STRUCTURE/CONTROL

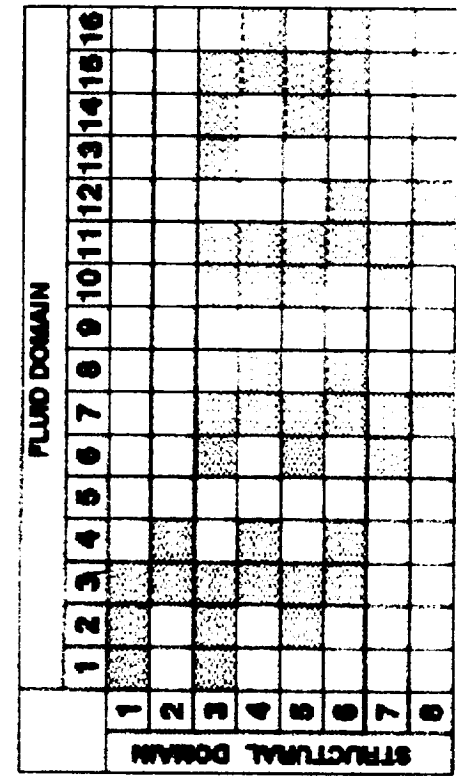


An Intercube Communication Between Fluid and Structural Domains

Surface grid decomposition (Fluid)

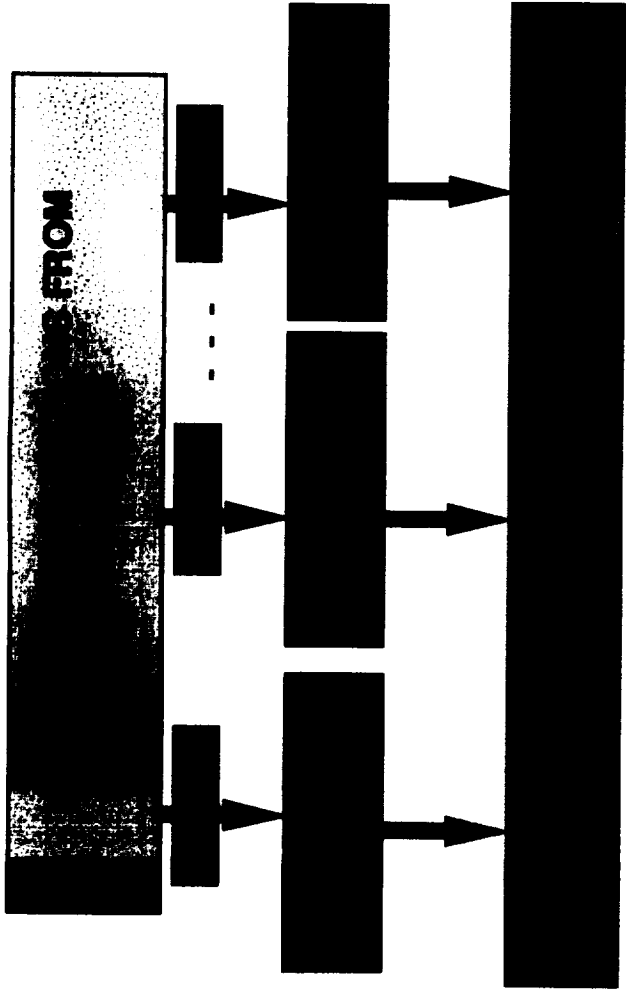


Finite element mesh decomposition (Structure)



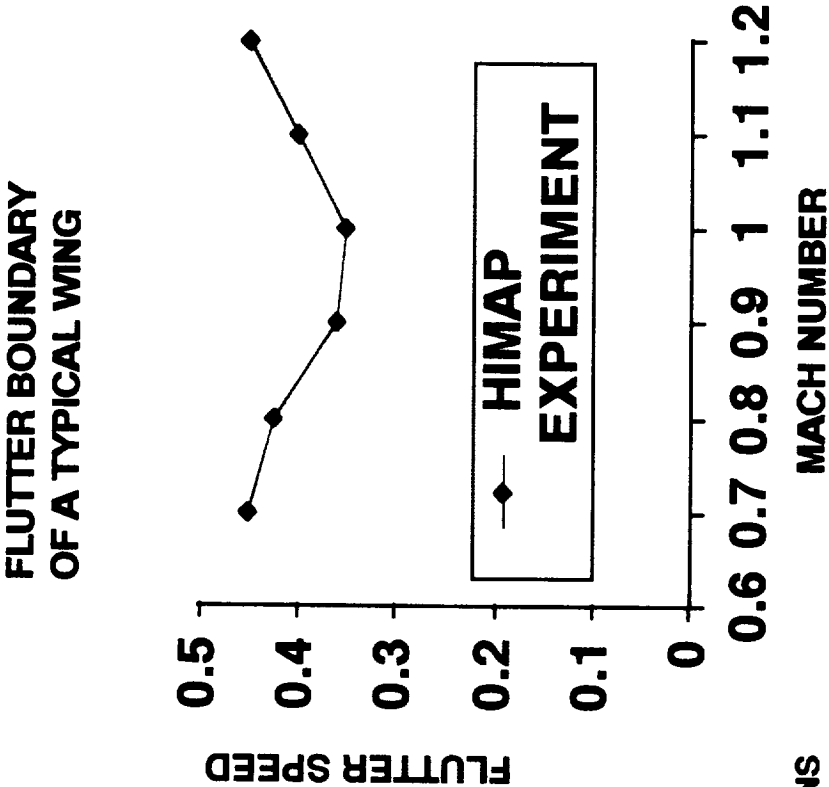
☒ active communication
☐ no communication
 1 - 16 : processor numbers

EXAMPLE FOR UNCOUPLED COMPUTATIONS



■ N MODES = NUMBER OF MODES X
 ■ NUMBER OF FREQUENCIES SELECTED

■ EACH CASE MAY HAVE DIFFERENT FLOW CONDITIONS

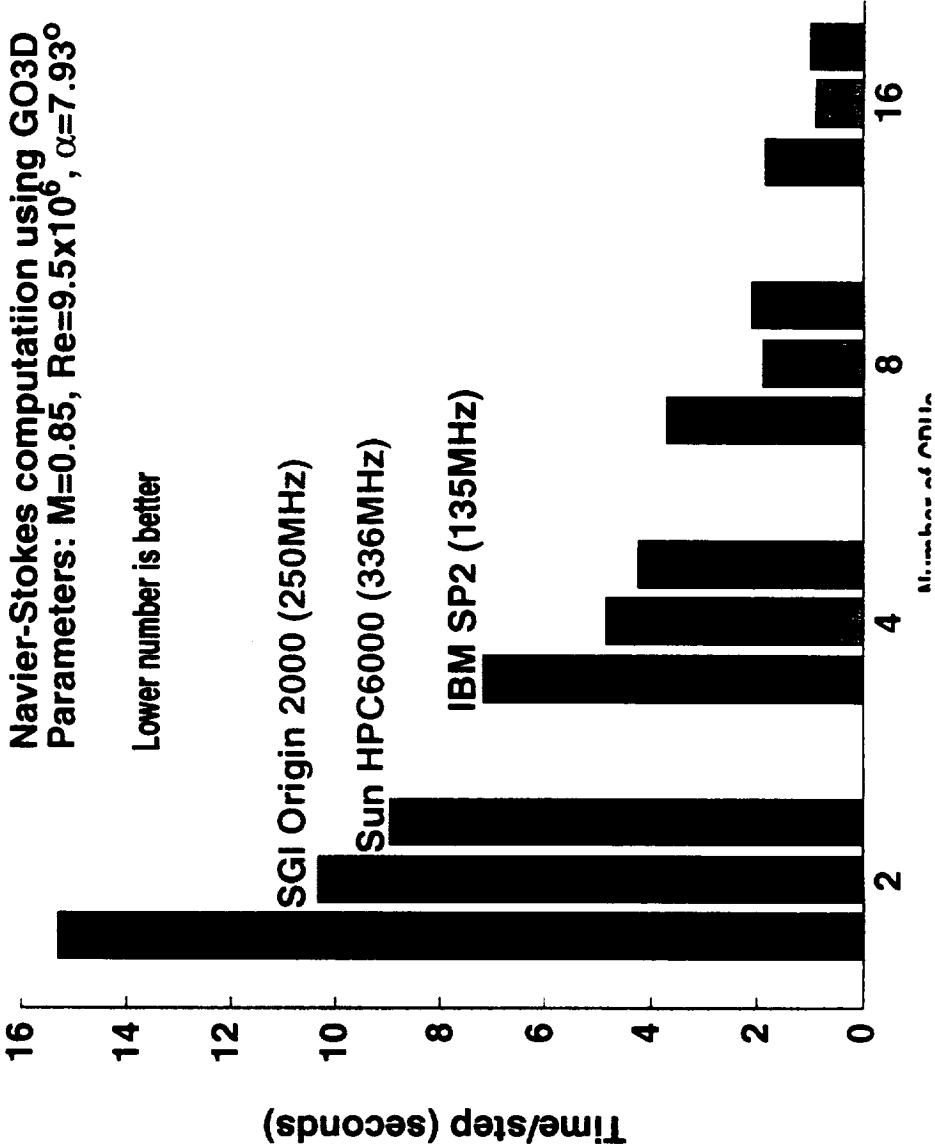


NOTE : 7 GFLOP PERFORMANCE ON 160 NODES ON IBM SP2
 SUITABLE LOW- FIDELITY COMPUTATIONS TO FILL DESIGN SPACE

PORTABILITY AND PERFORMANCE OF HiMAP

Coarse Grain Parallelization
Wing-Body Configuration
510,000 total grid points
Navier-Stokes computation using GO3D
Parameters: $M=0.85$, $Re=9.5 \times 10^6$, $\alpha=7.93^\circ$

Lower number is better



CONCLUSIONS AND FUTURE PLANS

- **A BASE MULTIDISCIPLINARY ANALYSIS PROCESS FOR CURRENT AND FUTURE NEEDS OF AEROSPACE INDUSTRY IS DEVELOPED**
 - **PORTABLE**
 - **SCALABLE**
 - **FLEXIBLE**
 - **MODULAR**
 - **SUITABLE FOR HIGH/LOW FIDELITY COMPUTATIONS**
- **WITH IT AND HPCC MIDDLEWARE CAN BECOME A CORE COMPUTATIONAL TOOL FOR SPACE APPLICATIONS**
 - **TRANSONICS, AEROTHERMOELASTICITY, REENTRY**
- **CAN SERVE AS AN IMPORTANT RESEARCH TOOL TO DEMONSTRATE IPG TO AEROSPACE AND OTHER ENGINEERS**
 - **IPG TOOLS SUCHAS GLOBUS ARE COMPATIBLE WITH HIMAP/MPI**
- **WITH OBJECT ORIENTED IT HIMAP CAN SERVE AS AN ANALYSIS MODULE FOR GLOBAL DESIGN TOOLS**
 - **DESIGN FOR SAFETY (DFS)**
- **CONTINUE DEVELOPMENT WITH HPCC AND IT PROGRAMS AND APPLY FOR SPACE AND DOD (UCAV, AWS, ASCI/FWV) PROJECTS**